ON THE SENSITIVITY OF BROADBAND REGIONAL SEISMIC PHASES TO MULTI-DIMENSIONAL EARTH STRUCTURE: IMPLICATIONS FOR PHASE IDENTIFICATION

Peter Goldstein, Joydeep Bhattacharyya, Doug Dodge, Gene Ichinose,
Richard Leach, Shawn Larsen, Arthur Rodgers
Lawrence Livermore National Laboratory

Sponsored by U.S. Department of Energy
Office of Nonproliferation and National Security
Office of Research and Development
Contract No. W-7405-ENG-48

ABSTRACT

An important challenge for seismic monitoring of nuclear test ban treaties at low magnitude is the development of techniques that use regional phases for detection, location, and identification. Accurate phase identification is a fundamental aspect of this problem. We compare 2-D finite difference synthetics and data for selected events in the Middle East, North Africa and Western US to show how structural features such as deep sedimentary basins, crustal thinning, topography, and high attenuation in shallow structure can have large effects on the timing and amplitude of regional phases.

We use moderate size (Mb~4.5-6) events whose source parameters are well constrained by local and far-regional to teleseismic data. This avoids the possibility of trade-offs between source and path effects. For example, we model the Mb-5.9 October 1992 Cairo, Egypt, earthquake at a station at Ankara, Turkey (ANTO), using a two-dimensional crustal model consisting of a water layer over a deep sedimentary basin with a thinning crust beneath the basin. Despite the complex tectonics of the Eastern Mediterranean region, we find surprisingly good agreement between the observed data and synthetics based on this simple two-dimensional model. We investigate the sensitivity of these synthetics to a number of features including 1) the thickness, velocity, and attenuation of the sedimentary basin, 2) the amount of crustal thinning beneath the basin, 3) the amount of attenuation, and 4) the presence of a water layer. We find that, for this region, the presence of a thick sedimentary basin has the most significant effects on the regional phases. Of particular note, Pg, which appears to have been extinguished in the data and individual synthetics, has actually been significantly delayed far into what is normally considered the Pg coda. The surface waves are dramatically dispersed by the presence of the basin. Sn also appears to have been extinguished in the data and synthetics, however, inspection of successive snapshots of the wavefield indicate that most of Sn has been converted to crustally guided waves that are superimposed on the Lg wavefield.

Crustal thinning beneath the basin also reduces the amplitudes of Pg and Sn, but its effects are less significant. The effects of large-scale attenuation are well approximated by a low-pass filter. The effects of the water layer are small but most noticeable in the surface waves.

These results show that we can use wavefield simulations to understand observed regional wave propagation phenomena and suggest that it may be possible to predict the behavior of regional phases and discriminants when we have an accurate model for the regional seismic structure.

Key Words: Seismic, Wave Propagation Modeling, Phase Identification, Regionalization, Middle East, Mediterranean, Caspian, Sedimentary Basin, Crustal Thinning, Attenuation, Topography.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48 for the Office of Research and Development, NN-20, within the Office of NonProliferation and National Security, NN-1.

OBJECTIVES

We have been developing the capabilities needed to model regional seismic signals in complex media (e.g., Larsen, 1995; Goldstein, et al., 1996; Goldstein et al., 1997; Goldstein and Dodge, 1999) so that we can help understand the physical basis for and performance of existing monitoring techniques. We also aim to use this improved understanding to help improve location techniques and help develop transportable seismic identification techniques. It may also allow us to predict the behavior of regional phases and discriminants in regions where there is limited data.

In this study, we investigate the sensitivity of regional phases in complex media to features such as deep sedimentary basins, crustal thinning, attenuation, and free-surface topography. We show how these features can affect regional signals and identify those features that have the greatest impact from a monitoring standpoint.

RESEARCH ACCOMPLISHED

The October 1992 Cairo, Egypt, Earthquake

We simulated the October 1992 Cairo, Egypt, earthquake in order to test our predictive modeling capabilities and to investigate the sensitivity of regional phases to complex regional structure, Figure 1. We began by simulating recordings of this earthquake at Ankara, Turkey (ANTO) using the epicentral location determined by the National Earthquake Information Center and a depth and mechanism (Figure 2) determined using broadband modeling of the P-wavetrain (e.g., Goldstein and Dodge, 1999).

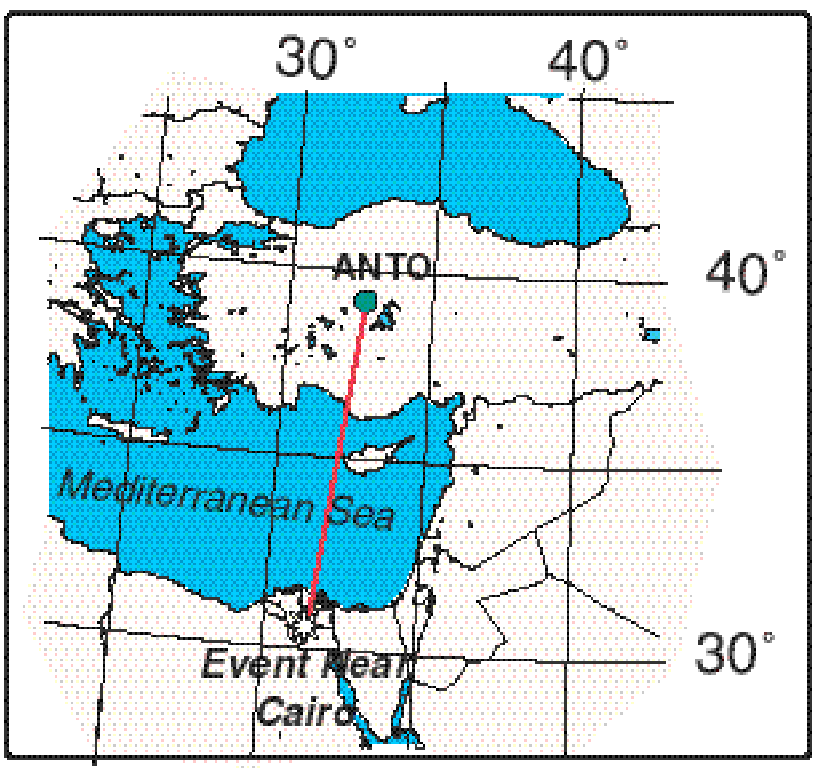

Figure 1. Map showing locations of the Mb-5.9 Cairo, Egypt, earthquake on October 12, 1992, and the seismic station at Ankara, Turkey (ANTO).

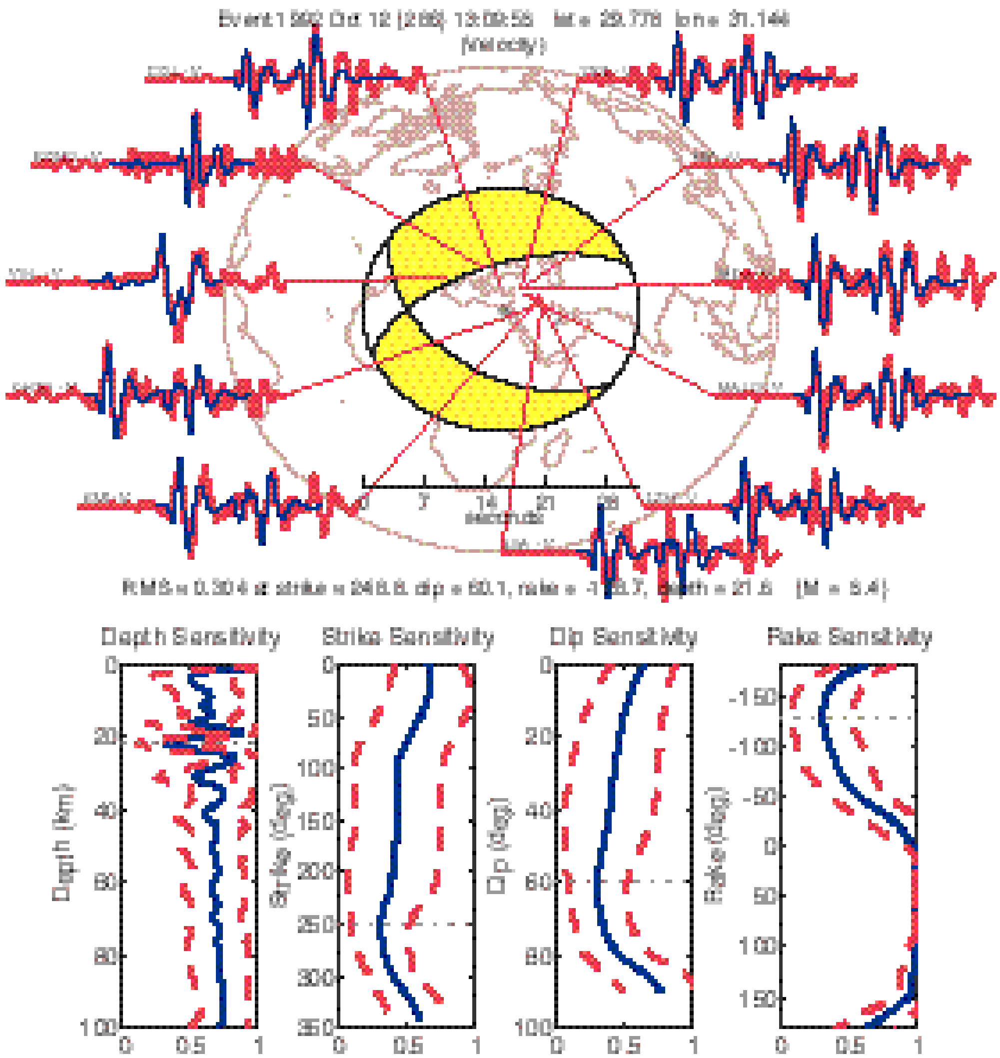

Figure 2. Far regional-teleseismic solution for the depth and mechanism of the October 1992 Cairo Earthquake. The upper part of the figure shows the focal mechanism and the waveform fits to the data. The sensitivity of the preferred solution to depth, strike, dip, and rake are shown in the lower part of the figure.

Based on the depth to basement and crustal thickness given in Cornell University Digital Database for the Middle East and North Africa (Barazangi et al., 1996), we developed a two-dimensional earth structure consisting of three crustal layers, the Mediterranean Sea, a thick sedimentary basin, and deeper crust that thins beneath the sedimentary basin (Figure 3). The upper mantle consists of a uniform velocity gradient extending to a depth of 100 km. At 1000 km, this structure is deep enough to model Pn and Sn but will not include the effects of any upper mantle discontinuities. In Figure 3, we compare the observed data with the simulations based on one- and two-dimensional models. We find excellent agreement between the observed data and the synthetic generated using the two-dimensional structure. In contrast, there are dramatic differences between the flat-layered approximation and the observed data. The excellent agreement between observed data and synthetic based on the two-dimensional model suggest that it may be possible to predict regional waveforms in regions where we have accurate estimates of the seismic velocity structure.

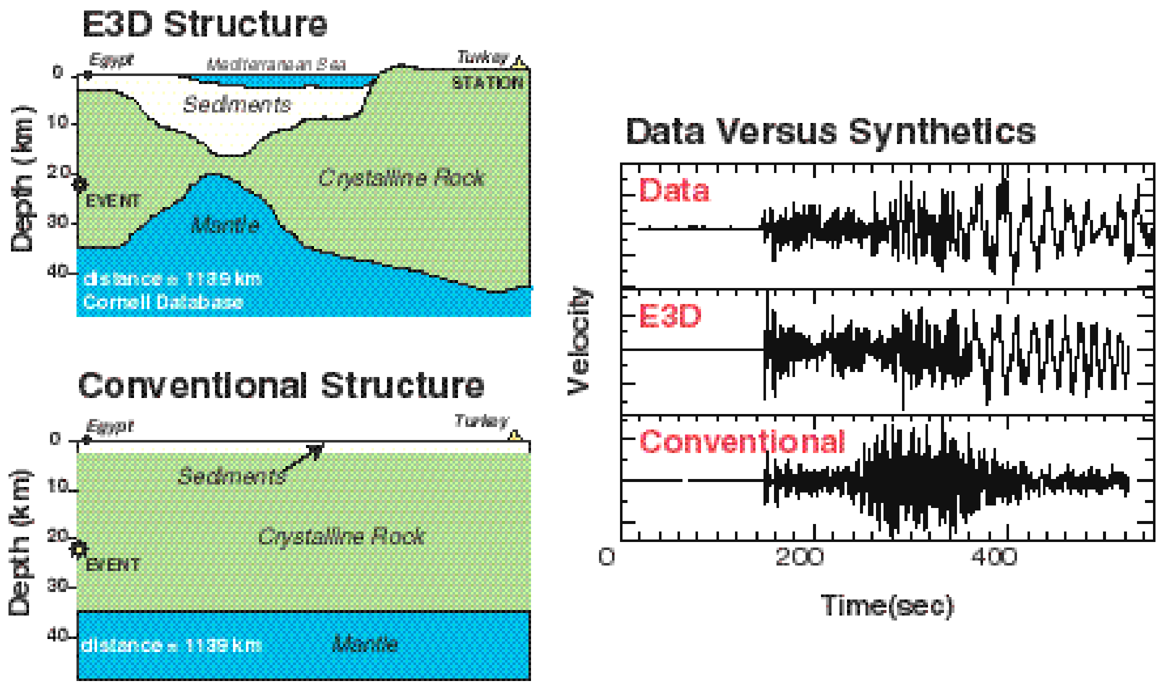

Figure 3 Comparison of one- and two-dimensional models and vertical component data and synthetics for the Mb-5.9 October 1992 Cairo, Egypt, earthquake as recorded at Ankara Turkey. The seismic station ANTO is indicated by the triangle near the upper right corner. The synthetic seismogram based on the laterally varying earth model provides a much better fit to the data.

Sensitivity of Regional Phases to Structure: Implications for Phase Identification

In this section, we describe our investigation of the sensitivity of our simulations of the Cairo, Egypt, earthquake to a number of features of the two-dimensional crustal model including: 1) the thickness and velocity of the sedimentary basin, 2) the amount of crustal thinning beneath the basin, 3) the amount of attenuation, and 4) the presence of a water layer. The effects of many of these features are indicated by the differences in the synthetic seismograms in Figure 4.

The most prominent differences are due to the deep sedimentary basin. Based on differences between simulations with shallow and deep sedimentary basins, this feature is responsible for a dramatic increase in the apparent dispersion of the surface waves. This reduces the amlitudes and significantly delays the Pg and Sn phases. The Lg phase is also enhanced by this feature due to a complex combination of scattering and conversion effects. Crustal thinning can also produce similar changes in Pg and Sn but has relatively minor effects on the surface waves.

An improved understanding of the physical basis for these effects can be obtained by a comparison of snapshots in time of the wavefield as it propagates through the different models (Figure 5). For example, snapshots for the preferred model indicate that the Pg phase doesn't really begin to propagate with significant amplitudes until after it passes the deepest part of the sedimentary basin. This observation is consistent with the idea that the basin absorbs and initially traps most of the P-wave energy with relatively steep incidence angles. This energy is then reradiated at the other end of the basin. Observed signals in the data and synthetics midways through the Pg window are consistent with this hypothesis. Similarly, the basin also acts like an excellent radiator of surface waves. We hypothesize that these signals, which appear to be dispersed, are actually the result of reverberations of the basin in a fundamental mode.

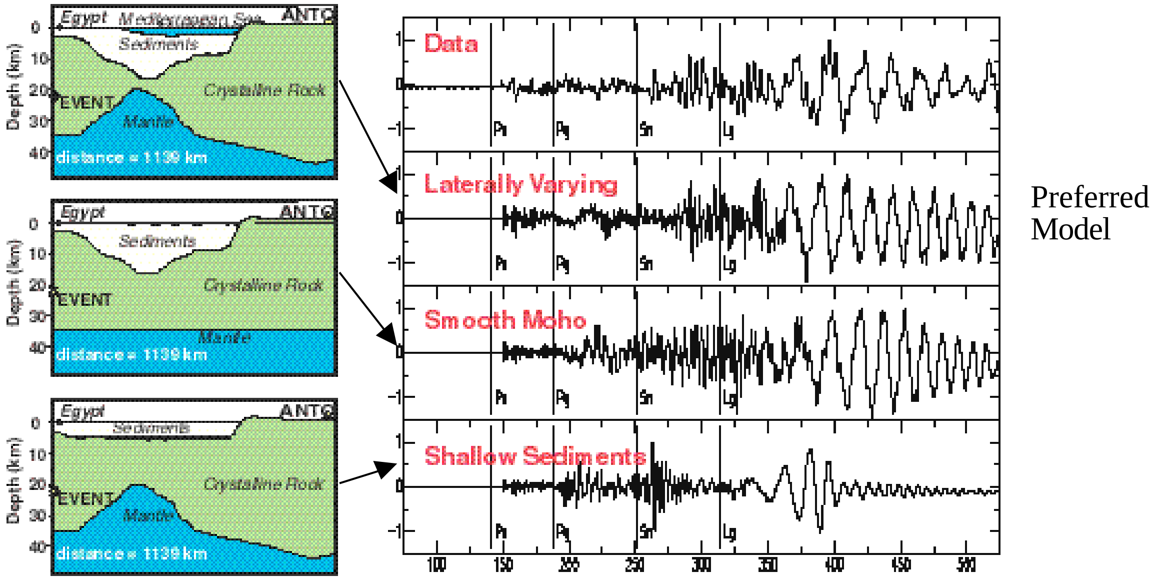

Figure 4. Comparison of vertical component data with synthetics for our preferred model, and models with shallow sediments, a smooth moho, and no water layer. Removing the shallow sediments from the preferred model leads to significant disagreement with the observed data.

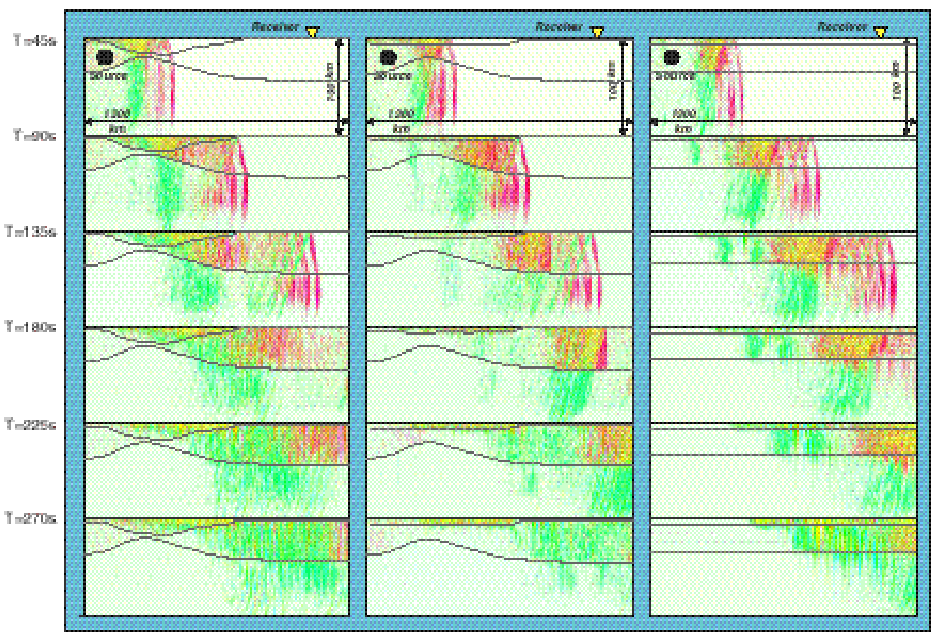

Figure 5. Comparison of snapshots of the wavefield at successive 30 sec time intervals in our preferred model, a model with shallow sediments and a flat layered model. P-waves are red and S-waves are green.

The effects of a variety of other features were also investigated including properties of the water layer, and attenuation. Most of the effects of these features were relatively small, however, as expected, the amount of attenuation in the shallow structure does have significant effects on the amplitudes of the crustal phases.

These result show how we can use simulations to understand regional wave propagation phenomena and suggest that it may be possible to predict the behavior of regional phases and discriminants when we have a reasonably accurate model for the regional seismic structure.

CONCLUSIONS

We have developed and are utilizing state-of-the-art, elastic wave propagation modeling capabilities to understand the physical basis of regional wave propagation phenomena. Understanding the physical basis of these phenomena is essential for developing transportable seismic identification techniques and for predicting the behavior of regional phases in relatively aseismic regions. Based on modeling of data in the vicinity of the Eastern Mediterranean, we find that regional phases (body waves, guided waves, and surface waves) are very sensitive to the existence of deep sedimentary basins. Crustal thinning also affects the regional body and guided waves but to a lesser degree.

REFERENCES

Barazangi, M., D. Seber, E. Sandvol, M. Vallve, 1996, “Digital database development and seismic characterization and calibration for the Middle East and North Africa”, PL-TR-96-2222, Phillips Lab., Hanscom AFB, Massachusetts, pp. 63.

Dziewonski, A.M., T.A. Chou, and J.H. Woodhouse, 1981, “Determination of earthquake source parameters from waveform data for studies of global and regional seismicity”, J. Geophys. Res., 86, 2825-2852.

Goldstein, P., and D. Dodge, (1999) “Fast And Accurate Depth And Source Mechanism Estimation Using P-Waveform Modeling: A Tool For Special Event Analysis, Event Screening, and Regional Calibration”, Geophys. Res. Lett. 8/99.

Goldstein, P., C. Schultz, and S. Larsen, (1997) “The influence of deep sedimentary basins, crustal thinning, attenuation and topography on regional phases; selected examples from the Eastern Mediterranean and the Caspian sea regions”, Proceedings of the 19th annual seismic research symposium on monitoring a CTBT, Annapolis, MD, September 23-25, 1997.

Goldstein, P., C. Schultz, S. Larsen, and L. Minner, 1996, “Modeling of regional wave propagation phenomena in the Middle-East and North-Africa and new analysis capabilities in SAC2000”, Proceedings of the 18th annual seismic research symposium on monitoring a CTBT, Annapolis, MD, September 4-6, 1995

Larsen, S.C., 1995, 3D MPP simulations in the earth sciences: seismic applications, LLNL Symposium on Distributed Computing and Massively Parrallel Processing.

Rodgers, A., and W.R. Walter, 1997, Regionalization and calibration of seismic discriminants, path effects and signal-to-noise for station ABKT (Alibek, Turkmenistan), submitted to the 19th annual seismic research symposium on monitoring a CTBT, Orlando, FL, September 23-25, 1997